High Density Infrared (HDI) Processed Coatings for Improved Wear and Corrosion Resistance

INDUSTRIAL MATERIALS FOR THE FUTURE (IMF) PROGRAM
Annual IMF Meeting
June 23 – 25, 2003

R.W. Smith	Materials Resources International, Lansdale, PA

Other Contributors

G. Ludtka and C. Blue	Oak Ridge National Laboratories
A. Wojcieszynski	Crucible Research, Pittsburgh, PA
L. Lherbier	Carpenter Powder Products, Inc. Bridgeville, PA .
K. Dobler	St. Louis Metallizing, St. Louis, MO
R. Mason	Ametek, Eighty Four, PA
P. Zagaeski	Lund International, Hudson, MA

MATERIALS RESOURCES INTERNATIONAL

UT-BATTELLE

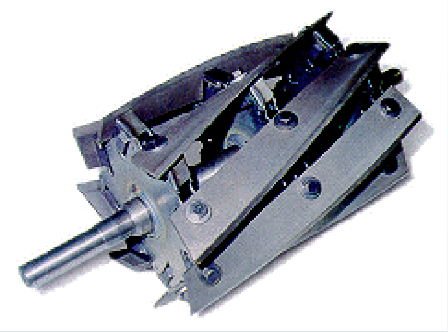
HDI-TLC Project Goals

- Develop wear and corrosion resistant coating methodology
  - → At lower cost with lower energy utilization, and
  - → Applicable for a range of applications

- Develop, evaluate, and understand how the High Density Infrared (HDI) heating technology improves wear coating systems
  - → Generate Thermophysical Properties
  - → Develop and Use High Thermal Flux Modeling to optimize thermal model input parameters

- Better understand densification & metallurgical bonding within HDI processed coatings
  - → Metallurgical Analyses: Microprobe, SEM-EDS, RBS, etc.

Industrial Applications



- Agriculture: blades (e.g., cutting corn, harvesting), biomass gasification systems
- Aluminum: roll coatings
- Chemical: tubes and pipes
- Forest Products: harvesters, slurry pumps, boilers, corrosion-resistant coatings for gasifier boiler tubes, etc.
- Glass: transfer lines (wear resistant), cyclones (corrosion as wear)
- Metal Casting: corrosion-resistant coatings for die casting
- Mining: earthmoving, material transfer systems
- Petroleum: pump body housings, pumping slurries, etc.
- Steel: boilers, weld overlays (BOF), steel processing and transfer rolls, etc.

Target Applications

- Agriculture: Blades
- Glass: Molds and Tools
- Metalworking: rolls
- Pulp &Paper: rolls and blades

PROJECT STATUS

- Demonstrated well-adhered, metallurgically *fused/bonded* claddings of various compositions
- Developments have shown that distinct differences in fusing behaviors of cladding compositions and their structures are related to the thermal and chemical properties leading to differences in wetting, adherence and densification
- Process Modeling Simulations are being developed to accurately predict thermal flux and optimize IR thermal processing parameters to enhance wear- and corrosion resistance

Technical Program

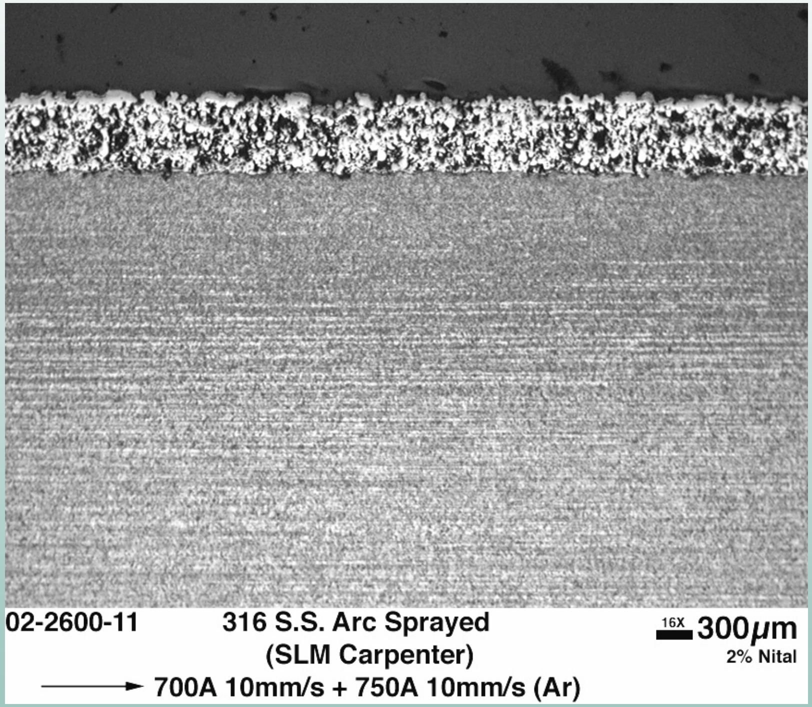
- Materials
- HDI Processing
- Coating Properties
- Application Assessment

Year 1 Scope

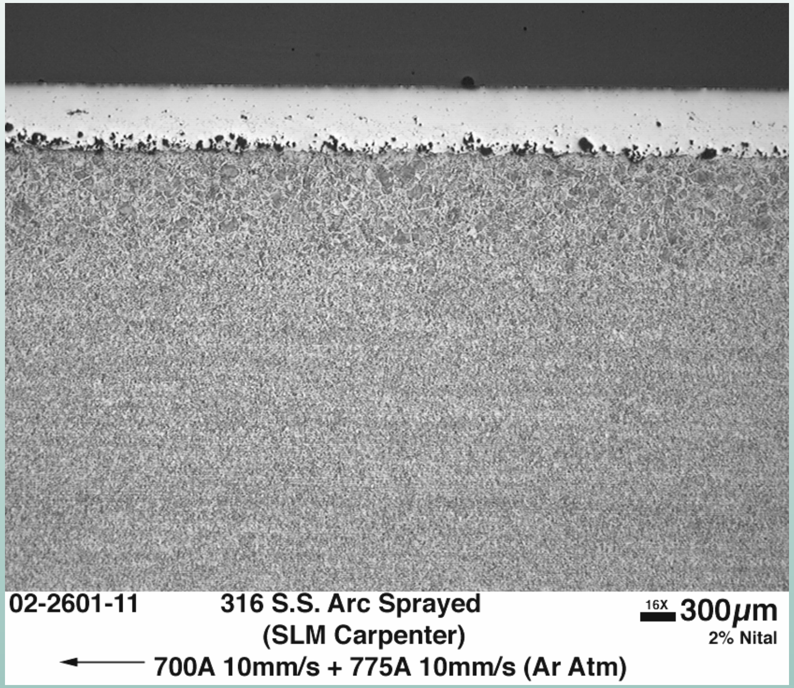
- Wear Coatings
  - WC and Cr-carbide composites
  - Tool Steel
- Corrosion Coatings
  - NiCr Self Fluxing
  - Stainless Steel
- HDI Processing
  - Precursor - Suspensions
  - Precursor - Thermal spray
  - Parameters / Process Controls
  - Feasibility

HDI Transient Liquid Processing

HDI Processing Dramatically Reduces Coating Porosity of Thermally Sprayed 316L SS - Etched



As-Plasma Sprayed

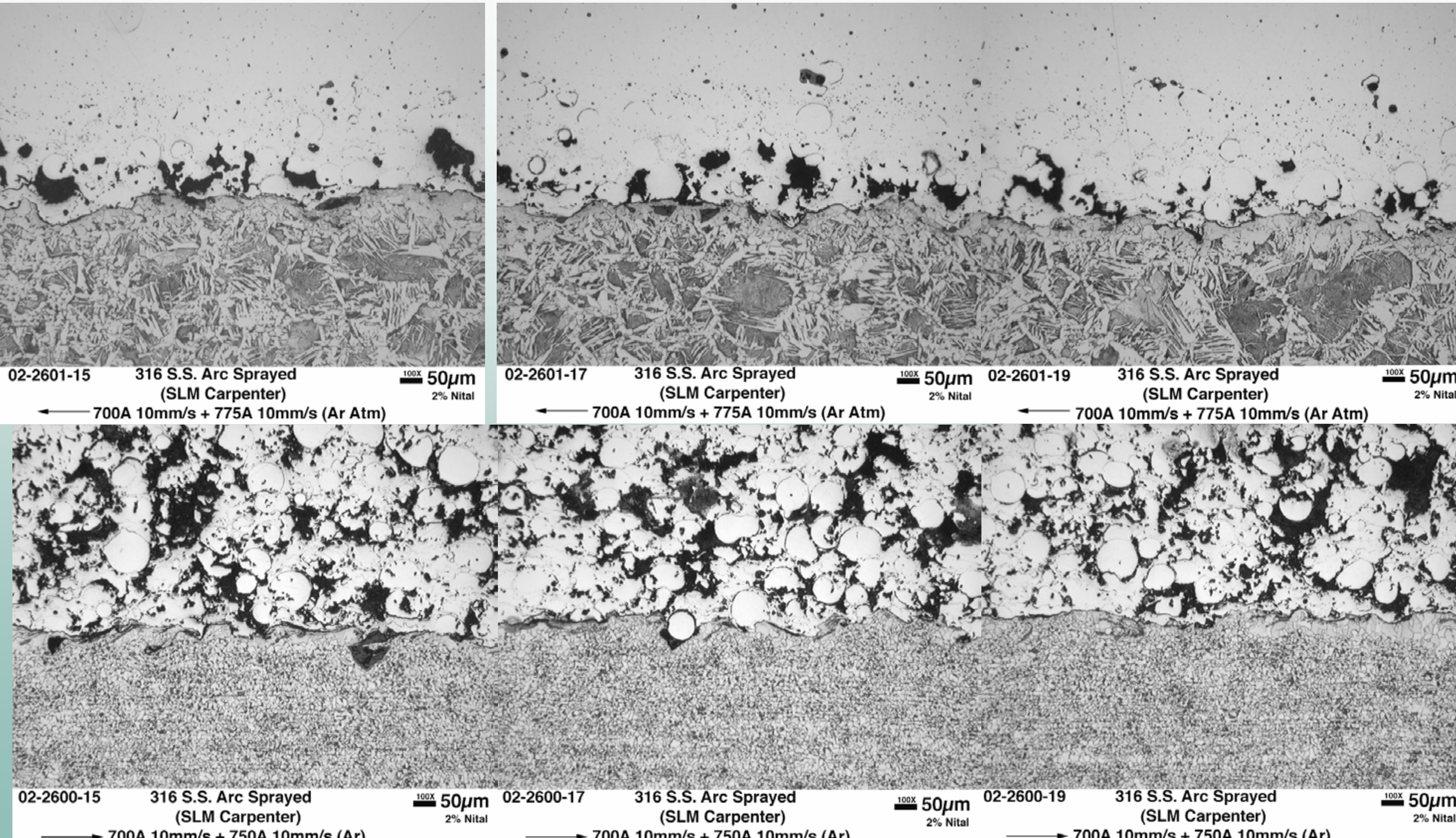


HDI Processed

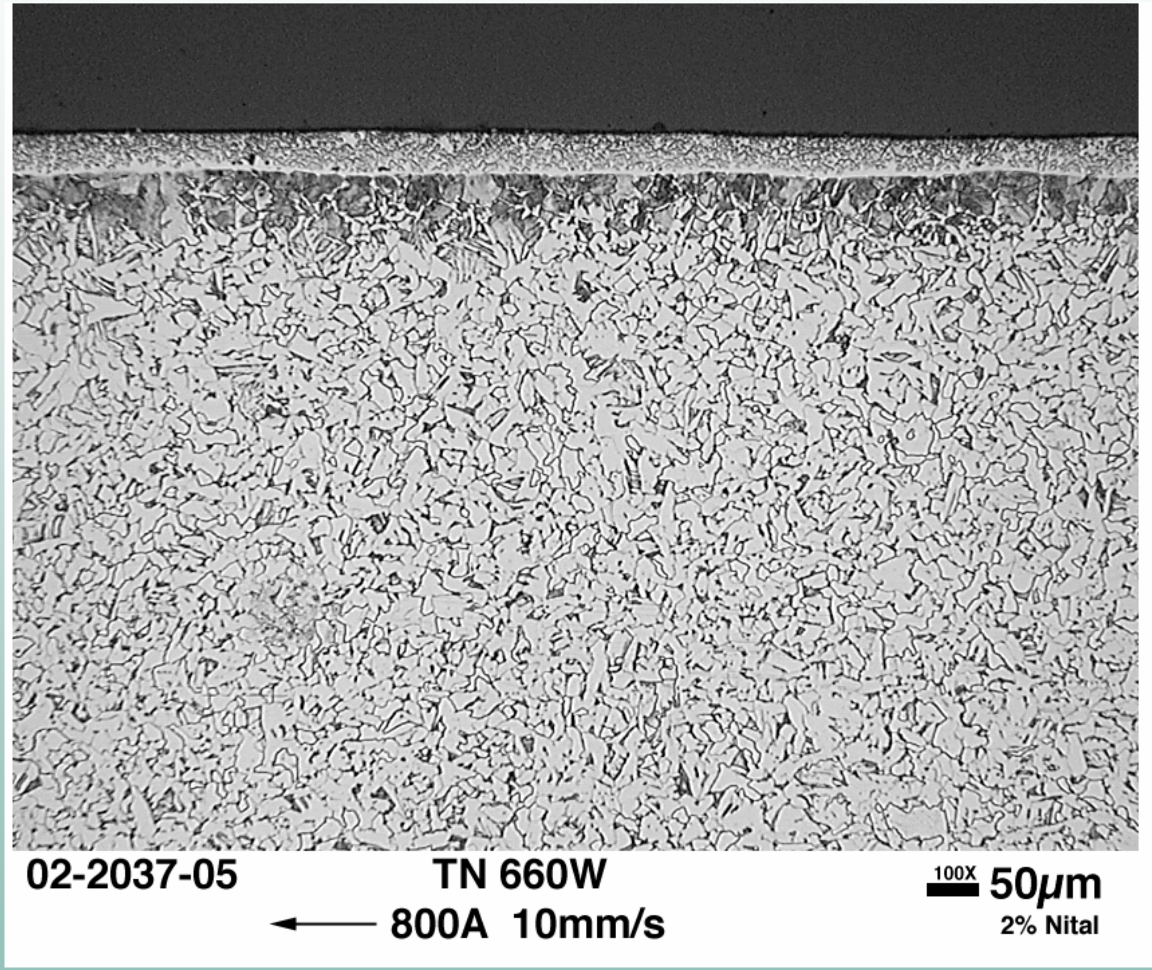
MATERIALS RESOURCES INTERNATIONAL

UT-BATTELLE

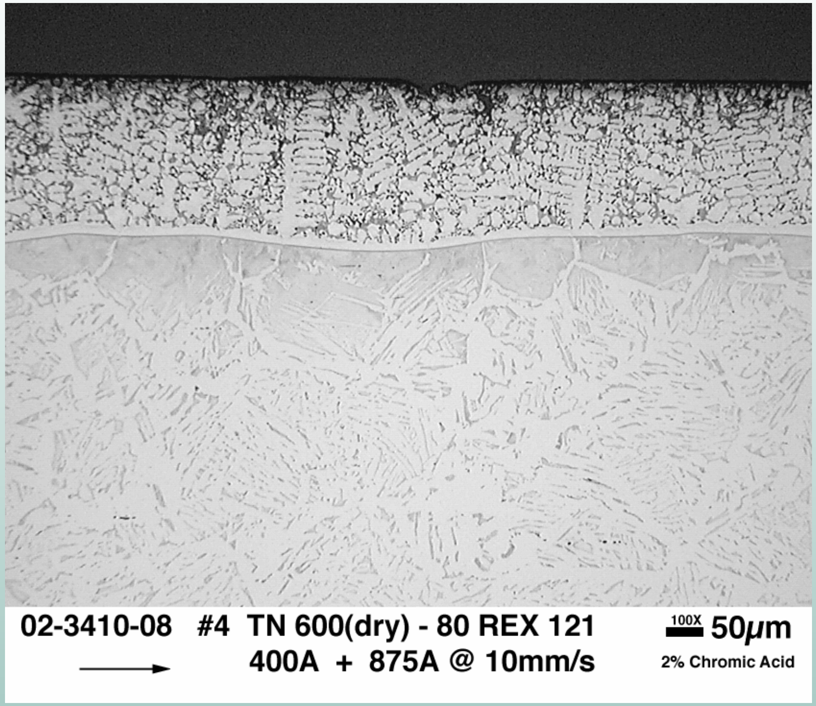
Thermal Sprayed Coating Porosity is Significantly Reduced with High Flux Thermal Processing - ETCHED



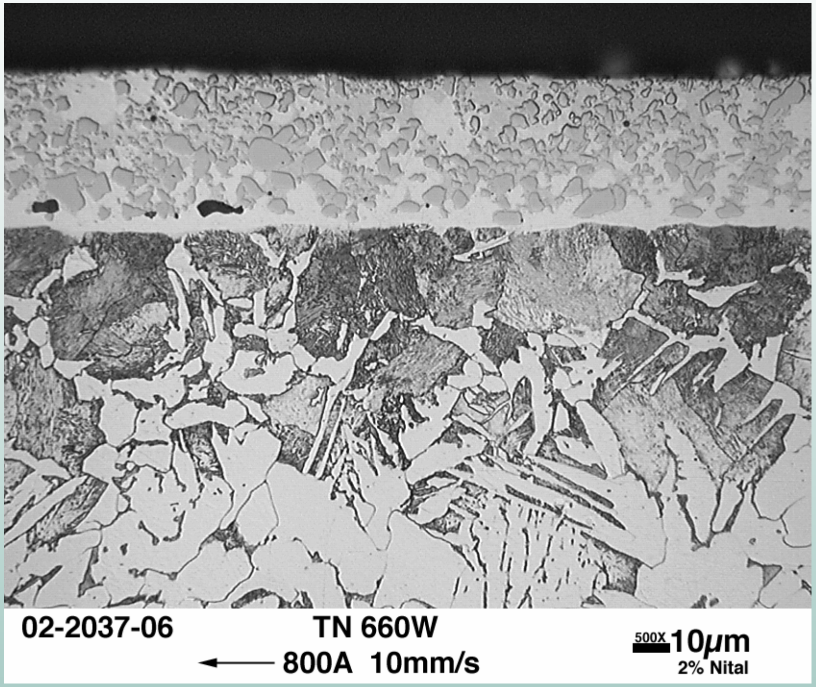
Suspension Sprayed Coatings
Sprayed and HDI Fused



Sprayed-on Suspension Coatings Blended with Steel Powders and WC Bond well to Steel Substrates and are being Investigated for Wear and Corrosion Applications



Steel Powder Suspension Coating

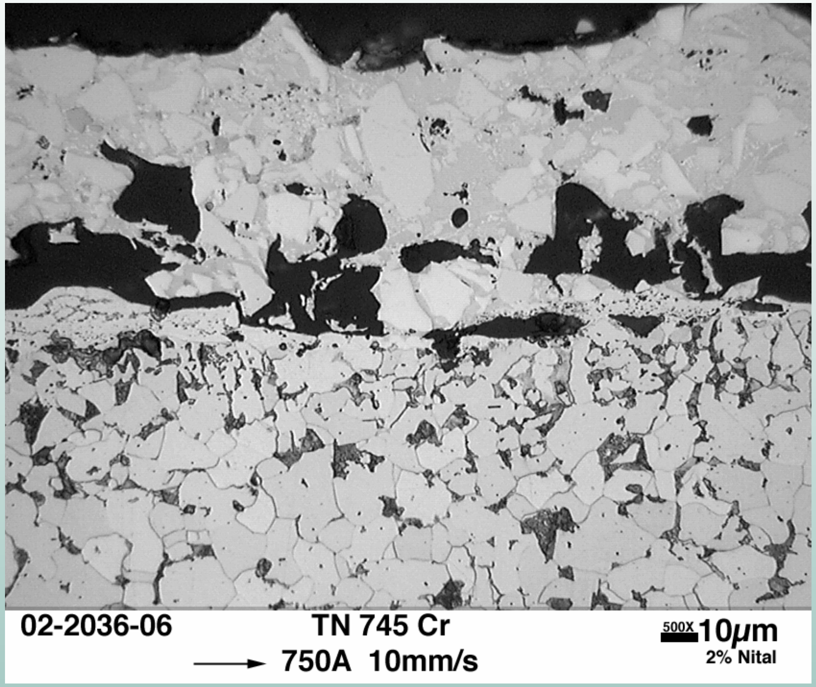


WC/Ni-P Suspension Coating

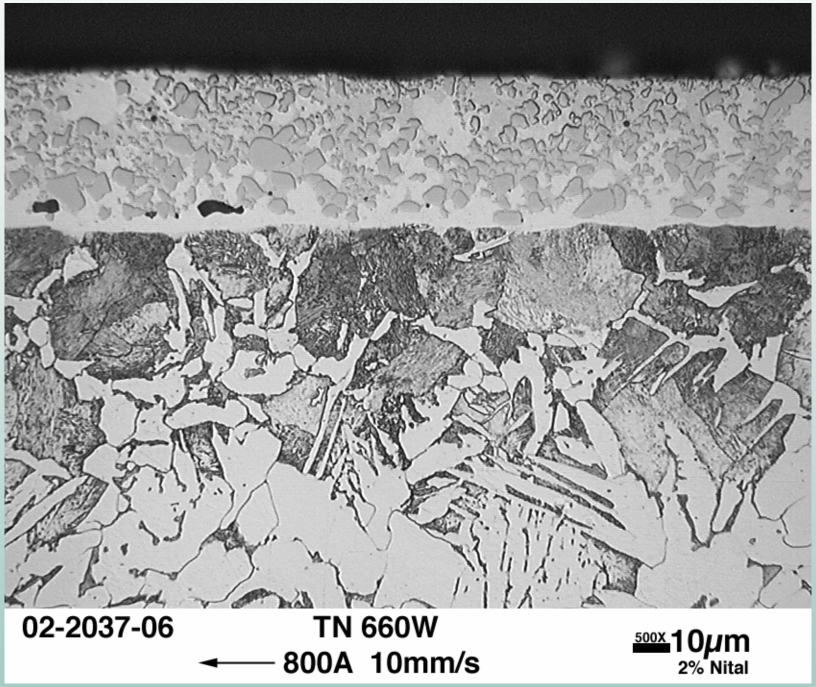
MATERIALS RESOURCES INTERNATIONAL

UT-BATTELLE

IR Processed Brazecoat™ Suspension Coatings on Hot Rolled Carbon Steel



TN745Cr



TN660W

Year 1 Conclusions

- Wear Coatings
  - Suspension / Carbide coatings were best precursor, but HDI process optimization needed.
  - Tool Steel / wetting issues and controls over thermal precursor needed
- Corrosion Coatings
  - NiCr self fluxing coatings / tolerant to HDI conditions.
  - Stainless steel are difficult and very dependent on thermal spray conditions and structures
- HDI Processing
  - Thermal spray precursor is very sensitive to structure and adherence before HDI processing.
  - NiCr self fluxing coatings / carbide suspensions worked best.
  - Wetting properties of liquid cladding is critical to post HDI coating.
  - Process parameter sensitivity dependent on precursor layer type.
- Need to focus on fundamentals / materials properties / modeling

Year 2 Action Plan

- Focus on fundamentals
  - Selected materials thermal properties
  - Thermal response / dynamics
- Model materials systems / Selected materials
  - NiCrBSi / WC-NiP suspension / Tool Steel / Stainless Steel
  - Ferrous base material only
- Process Modeling / Experiments
  - Thermal models
  - Instrumented experiments
- Objective(s)
  - Develop basic process understanding
  - Develop control / parameter space for materials based on cladding and base materials properties
  - Develop predictive capability

Basic Issues to Implement HDI Processing Technology

A fundamental understanding of the fusing process and its effects on the base material is necessary, considerations include

- *Liquid formation*
- *Wetting*
- *Heat Transfer*
- *Melting & Solidification*
- *Convective stirring effects on coating chemistry and structure*
- *Surface power input*
- *Interaction of molten surface with power input*

Basic Study Plan

<u>Focus on Material Sets</u>
- HVOF /thermal spray Self–flux alloy
- HVOF / thermal spray 316L SS & tool steel
- Carbide Suspensions

<u>Understand Interface</u>
Acoustic Microscopy
Selected coating thickness

Sessile Fusion /HDI Experiments
Select Materials

Characterize Material Thermophysical Properties

Heat Transfer Experiments

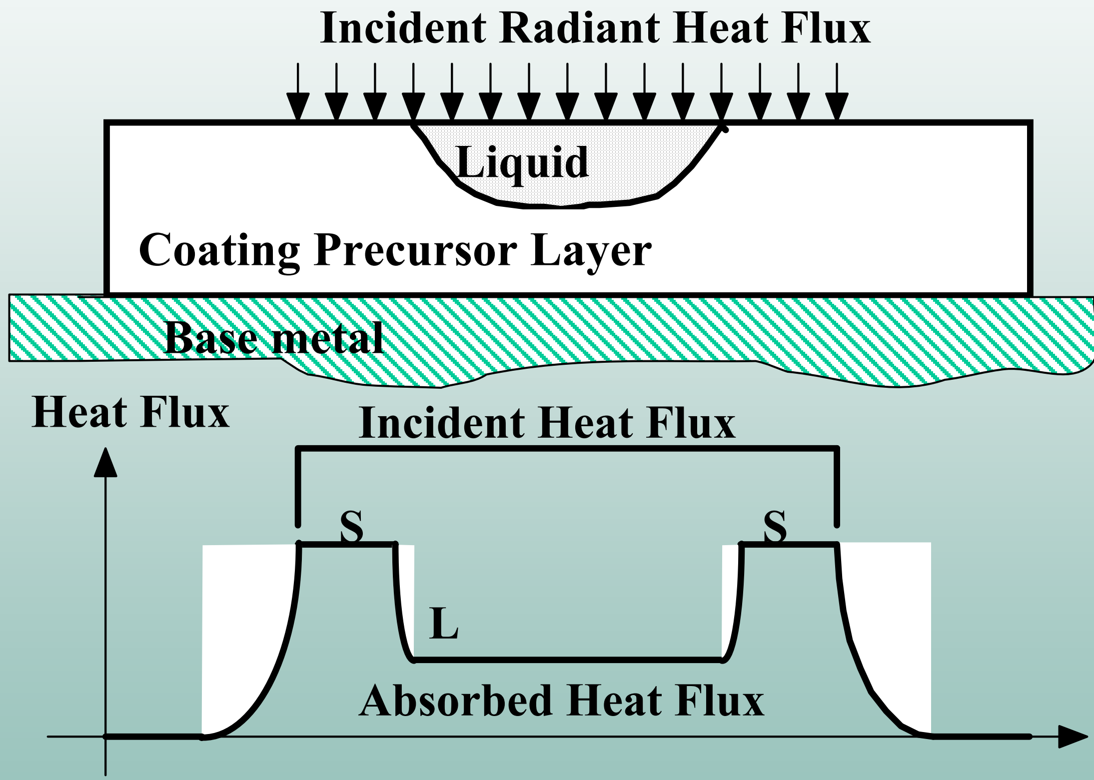
Thermal Modeling (ORNL)
Predict IR Process Parameters

Dynamic Fusion / HDI Experiments

Characterize Post-IR-processed Materials

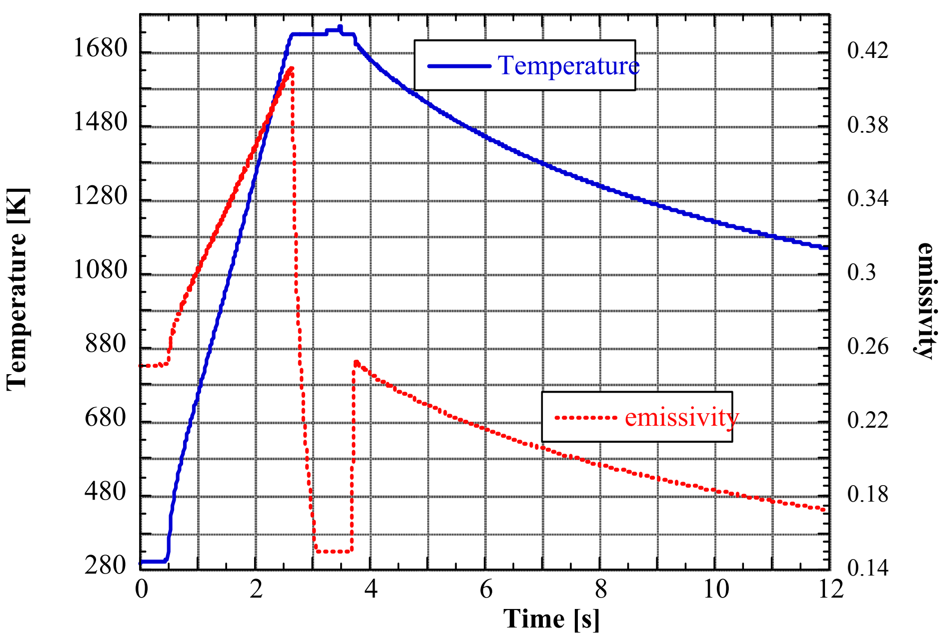
Apply, Fuse and Test Coatings on Industrial Components

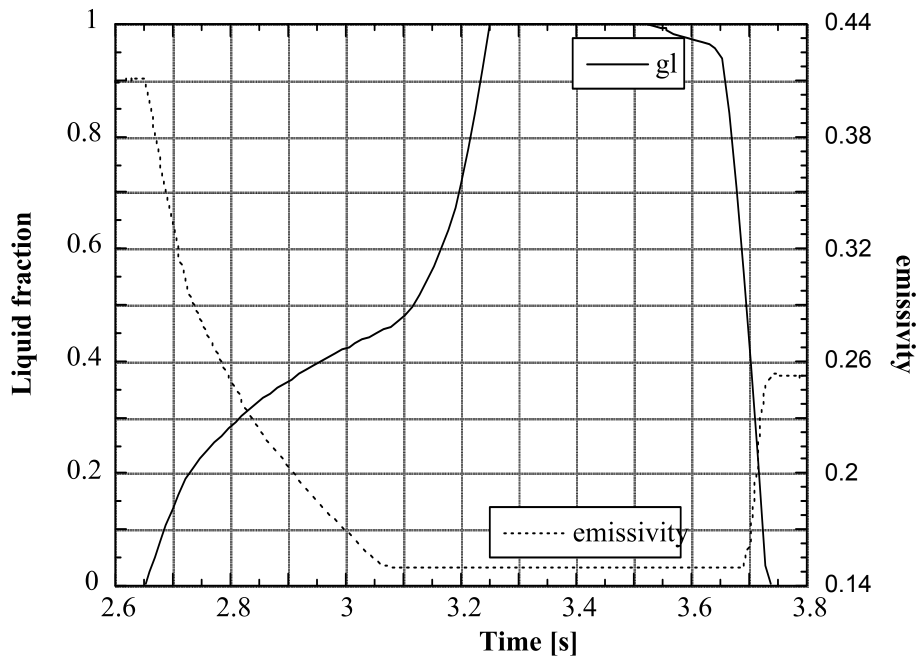
Schematic of Absorbed Heat Flux on the Surface at Melting



Met. Trans. JDK. Rivard et al, Submitted for Publn, (2002).

Thermal Flux Modeling
Developed to Predict the Heat Flux Input & Fusing Processing Parameters for Coatings





Surface Temperature Evolution and Emissivity during single 3 sec pulse heating cycle, melting, solidification, and cooling at Ni surface.

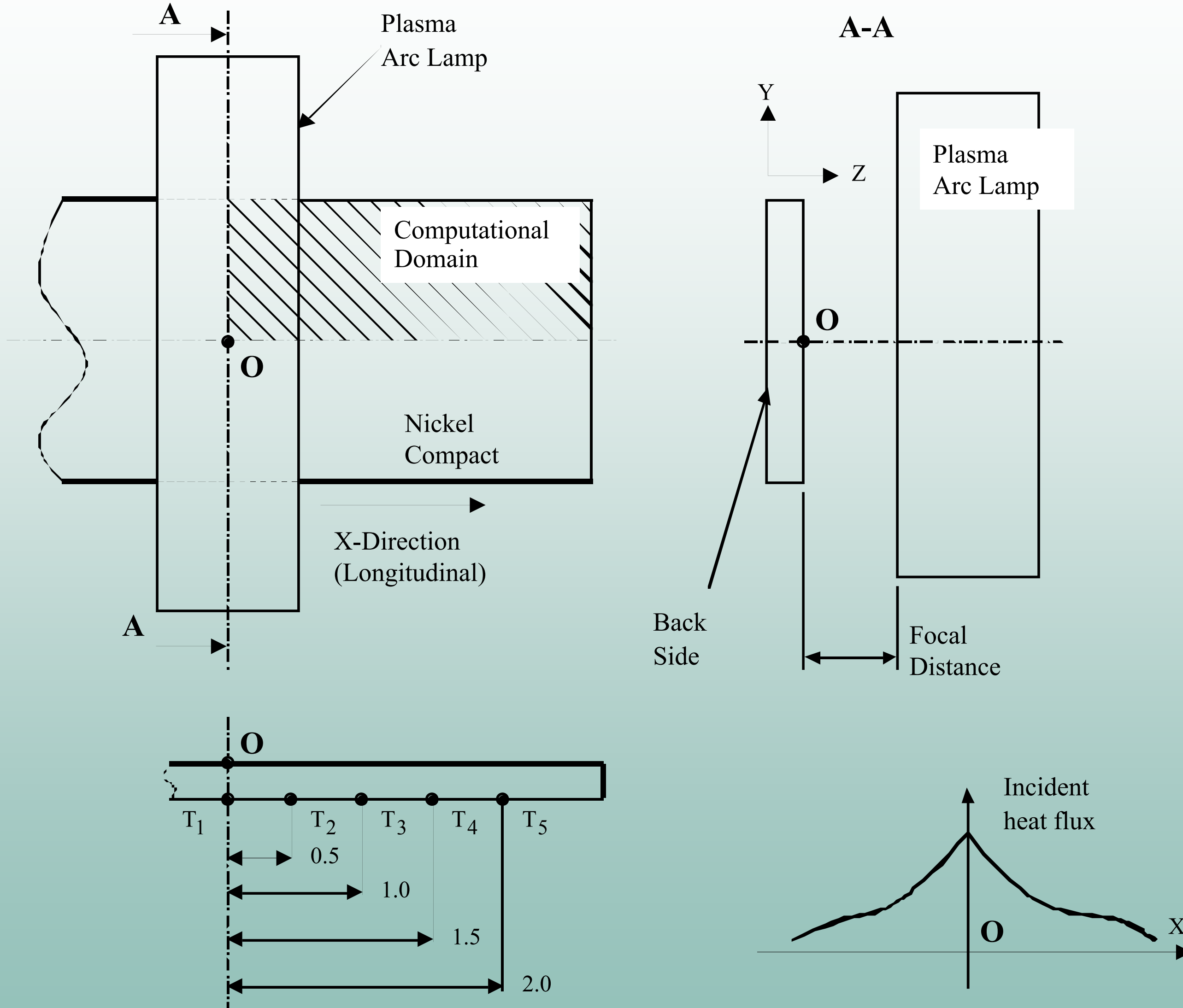
Liquid Fraction and Emissivity during melting, and solidification near Ni surface.

Oak Ridge National Laboratory
U.S. Department of Energy

MATERIALS RESOURCES INTERNATIONAL

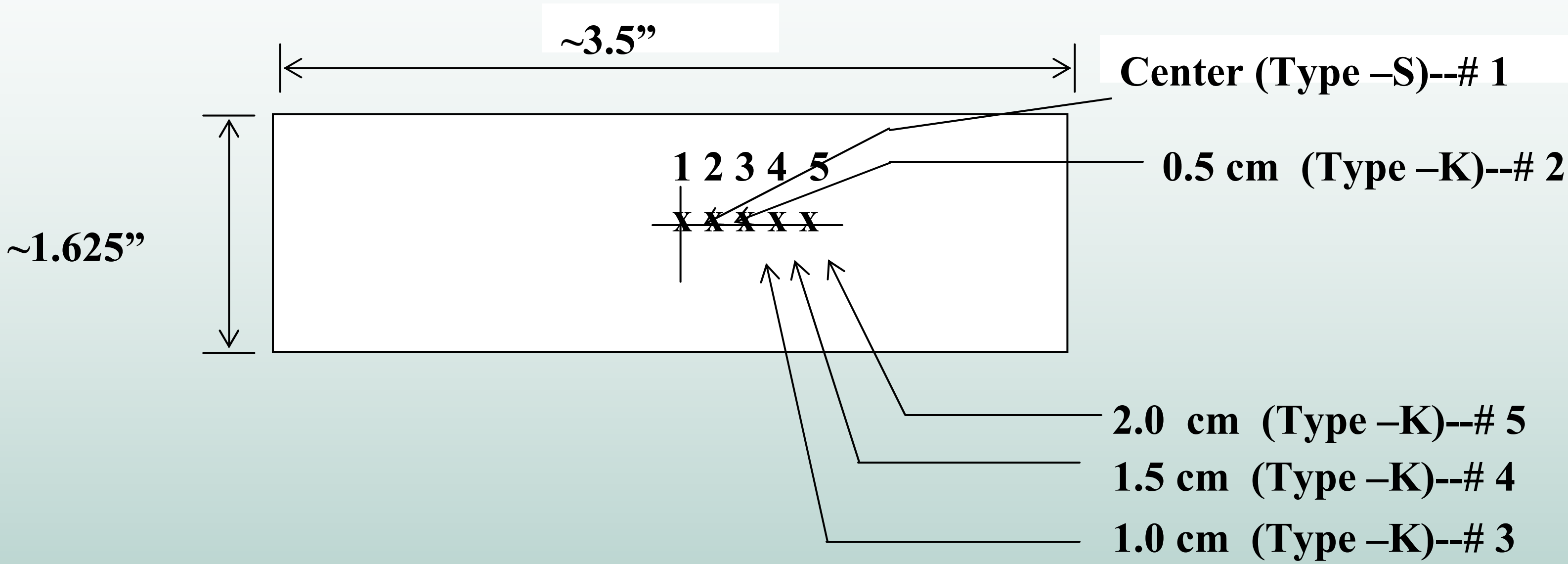
UT-BATTELLE

Schematic of Experimental Set-up



Met. Trans. JDK. Rivard et al, Submitted for Publn, (2002).

Thermocouple Set-up
Heat Flux Experiments



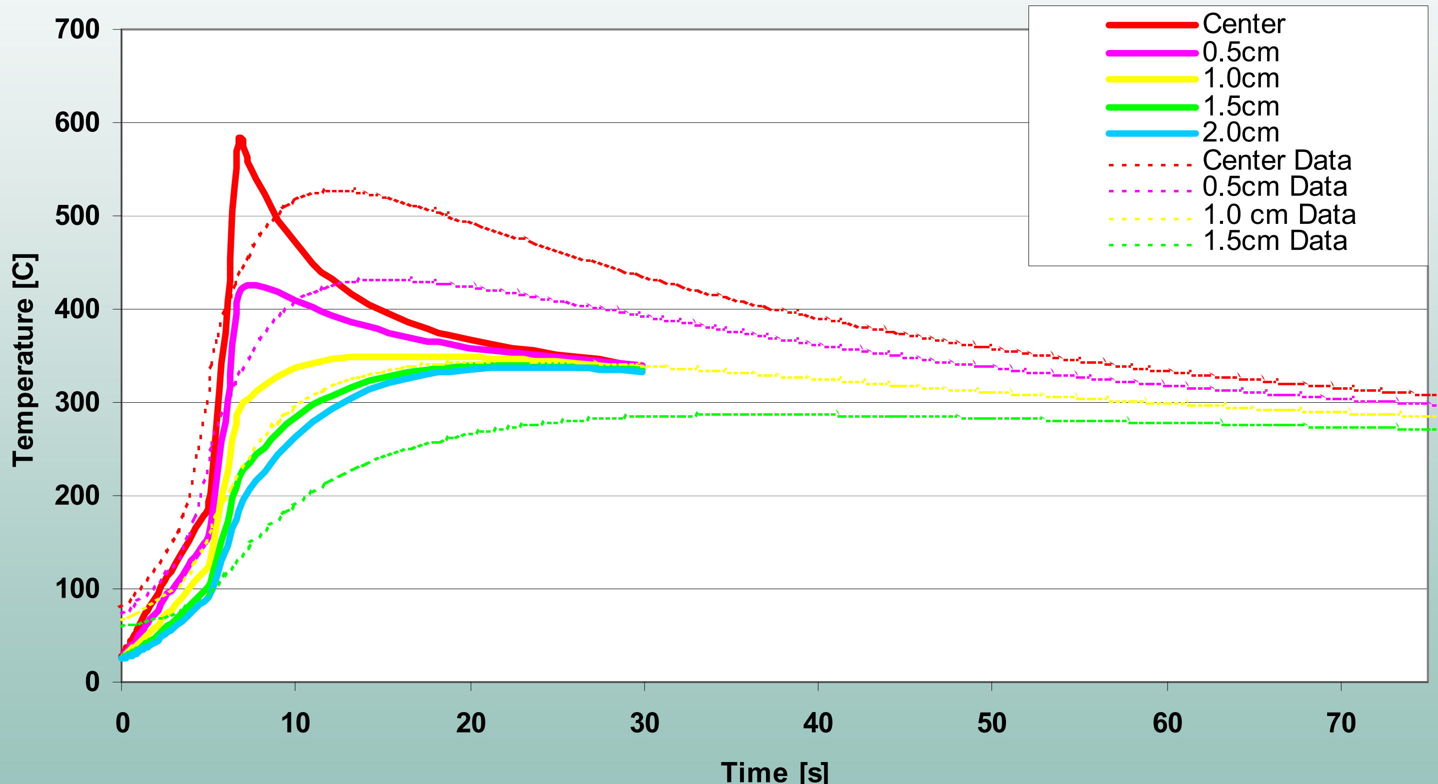
Experimental Set-up Thermal Trials

Side view

Experimental IR Set-up

IR Pulsed NiCr SelfFluxing Coated Sample

Process Modeling Simulations
In development to accurately predict and optimize IR Thermal Processing

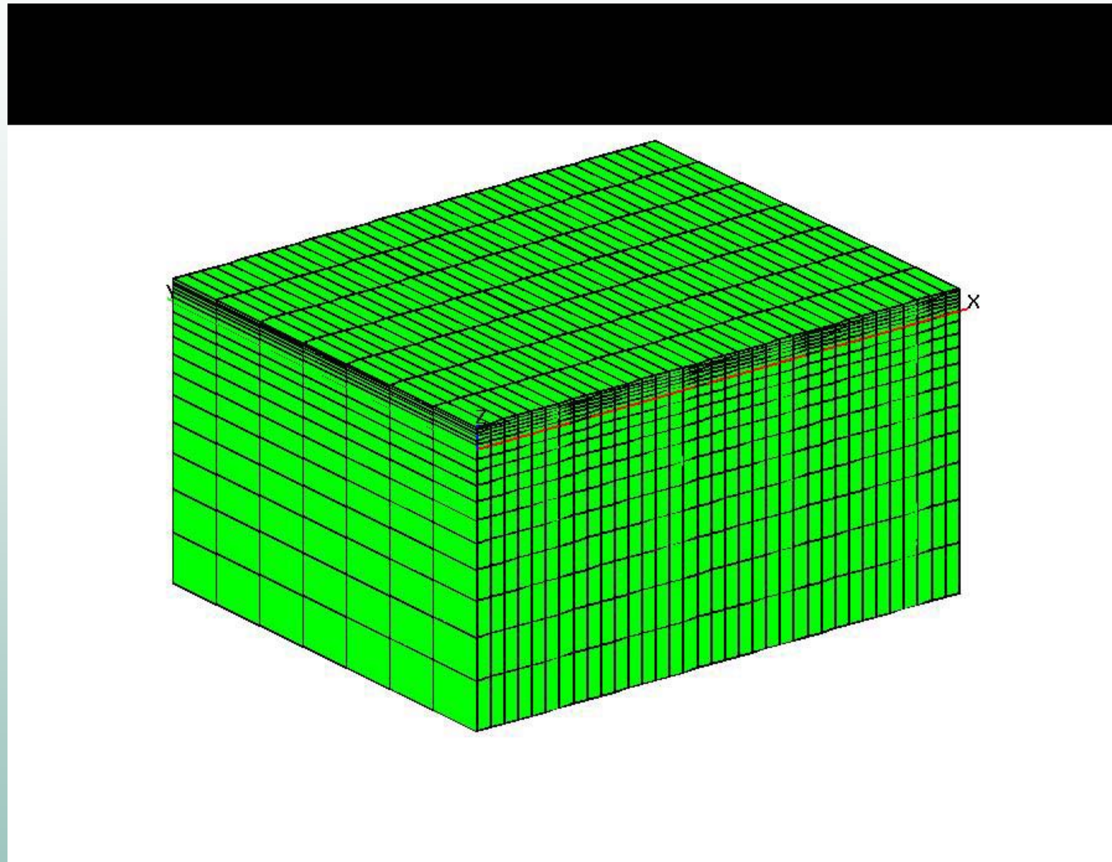


Used Ni properties/ for NiCrSiB and for TC's placed 1 mm below interface

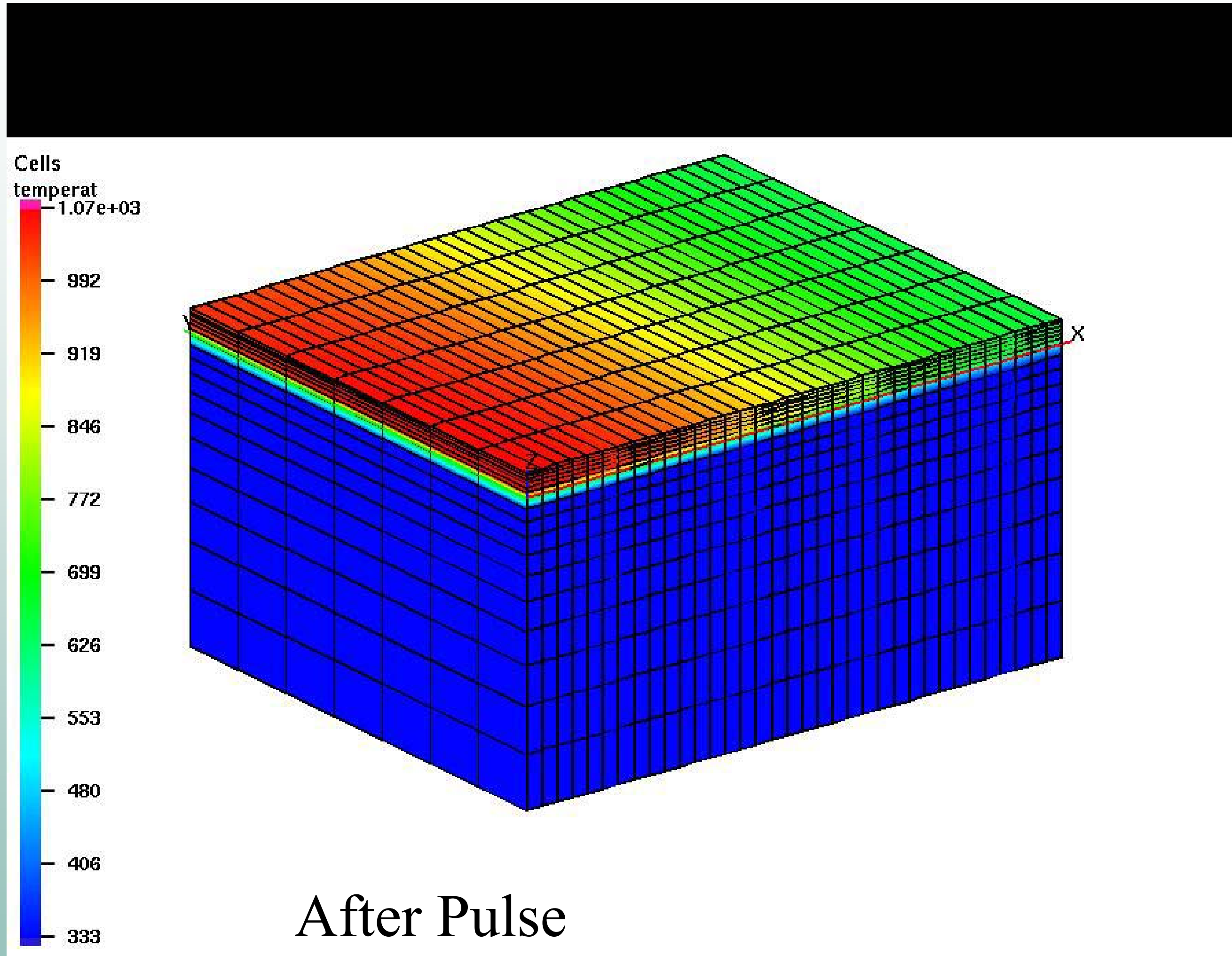
MATERIALS RESOURCES INTERNATIONAL

UT-BATTELLE

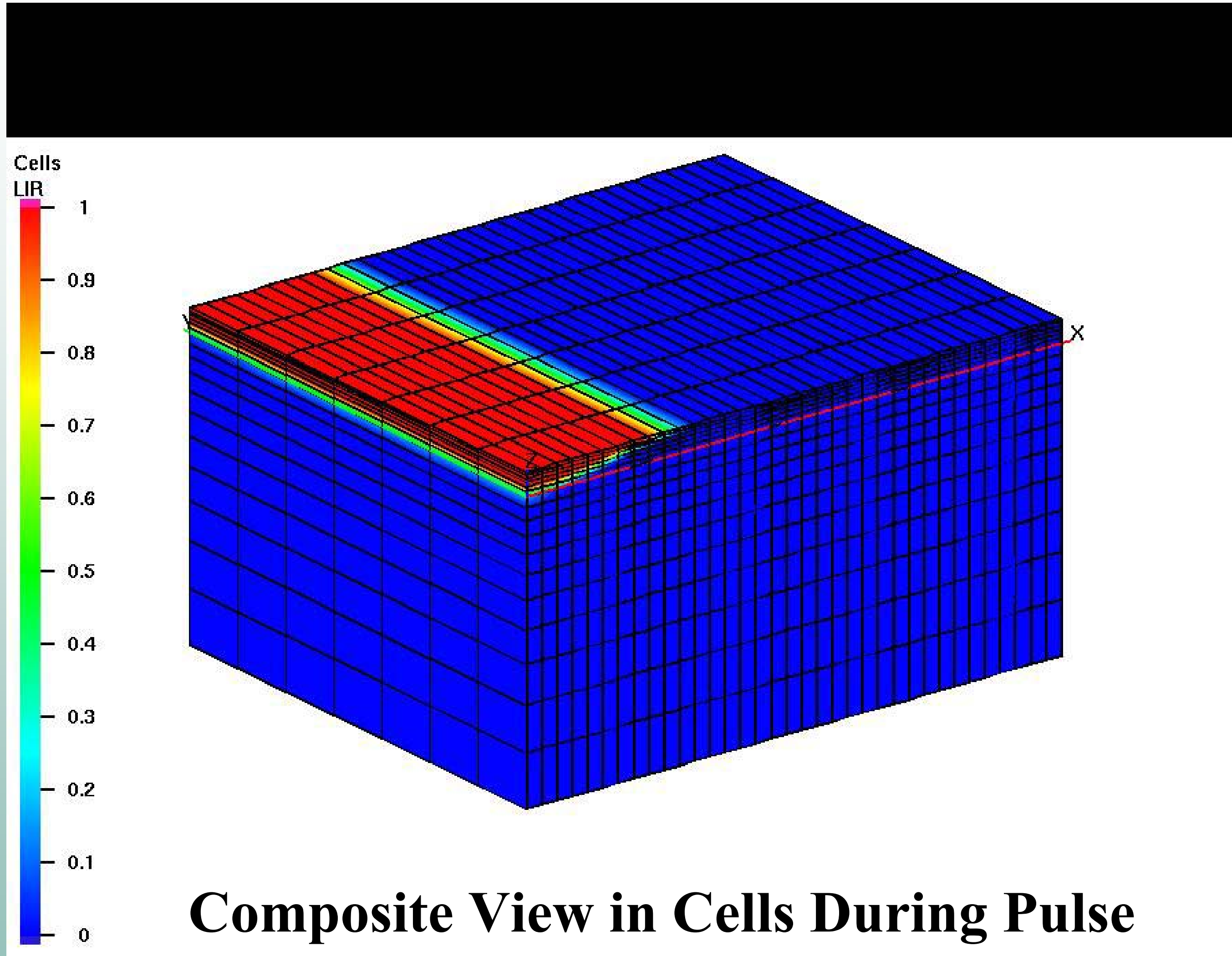
FEM Thermal Mesh



Temperature Profile



Fraction Liquid



Composite View in Cells During Pulse

Economic Issues and Benefits

- Heating Efficiency
  - Rapid heating rates
  - 90% energy efficient energy source
  - Lower mass to heat / surface only
  - Conservation of base properties / eliminate re-heat treat
- Retention of Base Mat’ls Shape & Properties
  - Flexible processing / mat’ls & shapes
  - In-field processing is viable
- A better understanding of HDI process leads to:
  - Understanding operational costs
  - Determination of Rates of fusion
  - Permits comparison of HDI processing costs to other methods

Estimate Energy Impact

Impact by the year 2020					
Energy Savings	Electricity	Gas	Oil	Coal	Total Energy Savings
Industry Group	[billion kW]	[billion ft^3]	[million barrels]	[million tons]	[trillion BTU's]
Petrochemical	0.53	16.7	0.2	0.15	25
Chemical	0.33	9.3	0.1	0.04	22
Other Manf.	0.27	8.7	0.1	0.04	20
Metal	0.20	7.3	0.07	0.04	10
Glass	0.27	8.0	0.08	0.04	12
Paper	0.07	2.0	0.01	0.01	3
Total Savings	**1.67**	**52**	**0.56**	**0.32**	**92**

Energy Cost Savings Based on Industry

Impact by the Year 2020	
Energy Savings ***Industry Group***	**Energy Savings [Million $/Year]**
Petrochemical (drilling / pumps)	190
Chemical (reactors / pumps)	110
Other Manf.	100
Metal (rolls / dies)	50
Glass (transfer lines / handling)	60
Paper (pulp processing / rolls)	15
Total Savings	**525**

Environmental Benefits

- Lowers energy consumption.
- Conserves base mat'ls / reduces replacements.
- Maintains efficiencies of equipment.
- HDI coatings could replace chromium hard coat coatings, eliminating hexavalent chromium processes.
- Thin HDI processed coatings conserve both energy and expensive coating materials.

Commercialization

- Coated Components
  - Service Partners could procure HDI systems
  - Partners could offer coating services
  - OEM's could install equipment or buy services
- Materials / Precursors
  - Partners provide coating materials / powders
  - Offer materials technology solutions

Commercialization Path

- MRi would establish an entirely new market for their BrazeCoat^{TM} materials
- MRi would adapt its marketing and sales to include the HDI/TLC method to apply these coatings
- Vortek lamp equipment use in thermal spray shop expected to replace some induction, flame, and/or furnace fusing
- ORNL's IR Processing Center is working closely with Vortek Industries (mfr of plasma arc lamp) and has extensive experience to assist in technology maturation and implementation
- ORNL would work with equipment manufacturer and a coating company to implement this technology

HDI-TLC Project Summary

- HDI shown to be an effective surface fusing heat source:
  Fast / Flexible / Focused / Economical
- Compatible with range of materials useful in target industries.
- Process is sensitive to precursor phases/inclusions
- Mixing/dilution with base metals is minimal.
- Basic Studies now initiated to understand metallurgical interactions with process.
- Heat Flux Model for 1 layer material has been developed, and 2 layer model is being developed
- In progress…
  - Coating Properties & Structures
  - Thermophysical Property Determinations
  - High Flux Model for 2 layer materials
  - Wear & corrosion planning
  - Application tests planning

MATERIALS RESOURCES INTERNATIONAL

UT-BATTELLE

Heat Flux Absorbed by Sheet Surface

$$q''(t,\vec{r}) = \varepsilon q''_{IR}\, f(t)\, g(\vec{r} - \vec{r}_o(t))$$

Where:

- **q''_{IR}** is the amplitude of the incident heat flux radiating from the plasma arc lamp
- **f(t)** describes the evolution in time of the lamp power
- **$r_0(t)$** the spatial distribution of the incident heat flux to the sample surface
- **g(r)** describes the motion of the lamp which indicates the spatial distribution of the incident heat flux to the sheet surface.